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AN ARTISTIC AUDIOTACTILE INSTALLATION FOR AUGMENTED MUSIC

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ABSTRACT

Music is an art form that organizes and presents vibrations that travel to the ears through air conduction. The range of audible vibrations (20 Hz to 20 kHz) [1] partly overlaps with the range of perceivable tactile vibrations (10 Hz to 1 kHz) [2], making it possible to feel the vibration of music as a pleasant by-product. In this project, we designed a series of vibrotactile installations that respond to specific note ranges. Musicians were then asked to compose a piece of music specifically for this installation to create a piece that could be heard and felt. Each composition was performed in front of a live audience. After the concert, the audience filled out a questionnaire about their experience. The results clearly indicate the different efficiencies of each installation and will help in designing better devices to optimize the tactile musical experience.

1. INTRODUCTION

Music is a multi-sensory experience that encompasses not only auditory elements, but also tactile sensations through vibrations. For individuals with hearing loss, touch plays an even more crucial role in the enjoyment of music. While traditional approaches to restoring sound perception include amplifying sound through hearing aids or stimulating the auditory nerve with cochlear implants, incorporating both audio and tactile stimulation creates a more immersive experience. Several products aimed at enhancing the musical experience through tactile stimulation have been developed, such as the Woojer vest, Ultrasonic Audio Syntac, the Subpack, and the Soundbox or has been proposed in research studies (for example [3, 4]). Our project aimed to create a product that utilized a user-centered design process by involving all stakeholders, including listeners, musicians, sound engineers, and engineers. Feedback was gathered on prototypes, ranging from simple to complex, and was collected through surveys through our collaboration with the University of Geneva at monthly concerts held in the Museum of Art and History in Geneva. Musicians were asked to create special pieces of music, while a sound engineer was asked to actively mix the sound for each installation. These insights were fed back to the engineers to develop new prototypes along the year.

2. THE VIBROTACTILE INSTALLATIONS

Master's students in Acoustic Engineering at the Technical University of Denmark developed two types of installations (see acknowledgment for full list). The first one invited the audience to recline and fully immerse in the vibrations across their entire body. The second allowed the audience to actively explore structures designed around a forest theme, enhancing the atmosphere of the surrounding paintings.

2.1 The full body immersion

2.1.1 The podium

The first prototype tested was a basic wooden platform (approx. 1x1x0.3m) made of 2cm thick plates. A broad-frequency response shaker (Clark Synthesis Gold) was placed on its interior center surface. We chose the Clark Synthesis Gold broad-frequency response shaker to enable the platform to produce both low-frequency vibrations and high-frequency music radiance. This decision was based on feedback from the musicians, who emphasized the importance of a device that could deliver both felt vibration and audible sound. Notably, we opted not to use any additional loudspeakers during the show. The audience was invited to recline on the platform and focus on the sensations they experienced (see figure 1).

2.1.2 The Cochlear Chair

Due to feedback that the platform was difficult for older audience members to recline on, a wooden chair was designed. To maintain the organic feel of the platform, the chair was also made of wood. To elicit different resonance frequencies on different parts of the body, the chair was designed as a continuous shape using laser-cut 6mm plywood pine. A Clark Synthesis shaker was placed in the upper back, and a buttkicker near the legs was added for additional resonance (see figure 2). The initial acoustical analysis of this structure uncovered some interesting findings. Specifically, resonance was detected at 127 Hz in the upper back, 282 Hz in the lower back, 15 Hz around the buttocks, and 168 Hz at the level of the legs.

Figure 1. The Podium

Figure 2. The Cochlear Chair

Figure 3. The Throne

2.1.3 The Throne

The second prototype, known as the Wooden Throne, improves frequency selectivity and reduces vibration damping by separating the vibrations from the body-supporting structure. It also transmits vibrations directly to the user through sympathetic bars. The prototype was inspired by the "Kalimba Bed" [5] but improved upon it - the bars in the Kalimba Bed changed frequency once someone laid on it, while in the Wooden Throne, the bars were mounted on a beam with varying width and equipped with a broadband shaker. The bar length and beam width were designed to resonate independently at different frequencies between 400 and 900 Hz (see figure 3).

2.1.4 Cathedra

The final prototype was developed based on feedback from the first six concerts. It features a series of dowels that directly stimulate the audience's back and legs through the chairs. The sidebars have been reduced in size to improve accessibility for those with limited mobility. The chair is equipped with sympathetic bars that directly transmit vibrations to the users, enhancing resonance in the higher frequency range. Following testing, the importance of hand and forearm stimulation was identified, leading to the addition of armrests to the design (see figure 4).

2.2 The vibrating forest

The students of Technical University of Denmark were commissioned to create an installation for children based on the theme of the forest [6]. They developed a set of installations with varied resonance frequencies to provide multiple points of interaction with the music. The visual aspect was overseen by local artist Kiral World (kiralworld.com).

2.2.1 The Flower

A giant 1-meter diameter plywood flower was created, with petals designed to vibrate at specific frequencies (see Figure 5). At the center, a Clark Synthesis (Gold) shaker served as the "ovary."

Figure 4. Cathedra

Figure 5. The Flower

Figure 6. The Tree

2.2.2 *The Tree*

The "Tree," a structure for embracing, was created with a 2-meter tall metal rod and two shakers at 90-degree angles, vibrating the rod perpendicularly. The rod was adorned with 24 wooden panels (Figure 6) connected with perpendicular metal bars, each resonating at different frequencies based on the rod's mode of vibration. A 10ms delay was added between the two shakers to separate their vibrations.

2.2.3 *The Spiral*

A spiral installation was crafted using a CNC machine to cut the shape into a metal sheet. By suspending the center, a downward spiral effect was achieved. Inspired by the basilar membrane structure, the spiral features two-and-a-half turns and gradually decreasing width, with a thicker section at the top resonating at low frequency and a thinner section at the bottom resonating at high frequency (Figure 7). A shaker was attached to the top of the spiral.

3. METHOD

Each month, local musicians were invited to spend three days composing a piece specifically for the audio-tactile art installations at the museum. These artists were selected for their adaptability to new composition environments, and their music encompassed a wide range of styles, from purely acoustic instruments or vocals to purely electronic. The process typically began with improvisation, recorded

Figure 7. The Spiral

by a full-time sound engineer and played back to the musicians for further experimentation with the installations. After several iterations, a new composition emerged, and two concerts were held Thursday nights, each lasting approximately 30 minutes with a limited audience of 25 people to allow for exploration of the installations. After each show, the audience was invited to provide feedback via a questionnaire.

The questionnaire consisted of 6 questions that participants rated on a 5-points scale of ”not agreed at all” to ”totally agreed,” except for the last question which was rated on ”not strong enough” to ”too strong. Our questionnaire was designed to be concise yet informative enough for the audience to provide valuable feedback. It was distributed by an external researcher, who emphasized the importance of honesty in improving the installations. Though participation was voluntary, the majority of the audience were willing to share their thoughts. At the end of the survey, respondents were given the option to provide a free-form description of their experience. Across four concerts, we received responses from 98 participants who completed at least one part of the questionnaire. Among these respondents, only four reported experiencing partial hearing loss.

1. *The vibrations enhanced my perception of the music.*
2. *I experienced varied musical elements through different parts of my body.*
3. *The vibrations were a distraction from the music.*
4. *The vibrations allowed for a more immersive musical experience.*
5. *The vibrations complemented the music.*
6. *The vibration intensity was: Not strong enough or Too strong.*

Installation	Nb of Evaluations
Podium	90
Cochlear Chair	50
Throne	29
Cathedra	28
Flower	47
Tree	12
Spiral	13

Table 1. Number of evaluations per installation

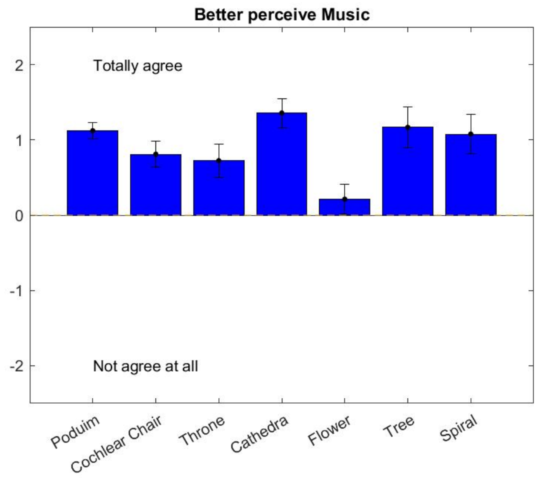

Figure 8. Ratings for the Question: *The Vibrations Enhanced My Perception of the Music*. The figure shows the absolute ratings on a 5-point scale, ranging from 2 (strongly agree) to -2 (strongly disagree), with error bars representing the standard error.

4. RESULTS

Data was collected from 5 out of the 10 concerts, yielding 98 participants with ages ranging from 14 to 85 (mean 42, standard deviation 15.3). The concerts were marketed as accessible to all, including those with disabilities, but only a few reported moderate hearing loss. The Audience was encouraged to try multiple installations during the concert. However, unequal availability of installations resulted in varying levels of evaluation. For instance, all concerts had access to six podiums, but the tree and spiral installations, created later, were only available during the last concert. The table 1 summarizes the number of evaluations for each installation. Although the Flower installation was only accessible during the last 2 concerts, it received a higher number of evaluations due to its capacity to accommodate 4 to 5 people simultaneously. On the other hand, the Throne, which was available throughout all concerts, received fewer evaluations due to its limited capacity.

4.1 Question 1: The vibration enhanced the music

This first question was designed to test the core objective of the project to enhance the perception of music. Figure 8 displays the average rating for all installations. All of them received a positive rating, indicating that on average, the participants felt that the vibrations enhanced their percep-

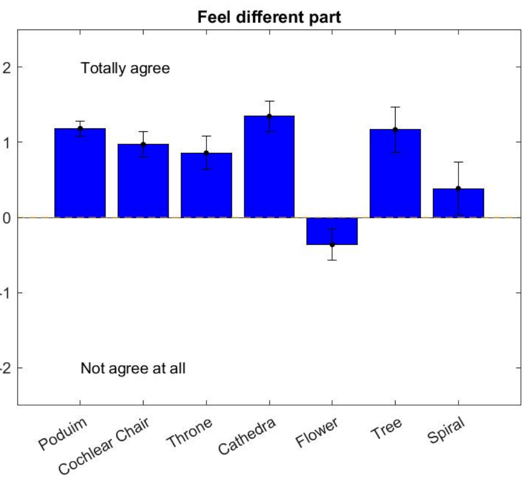

Figure 9. Ratings for the Question: *I experienced varied musical elements through different parts of my body*. See figure caption 8 for more information

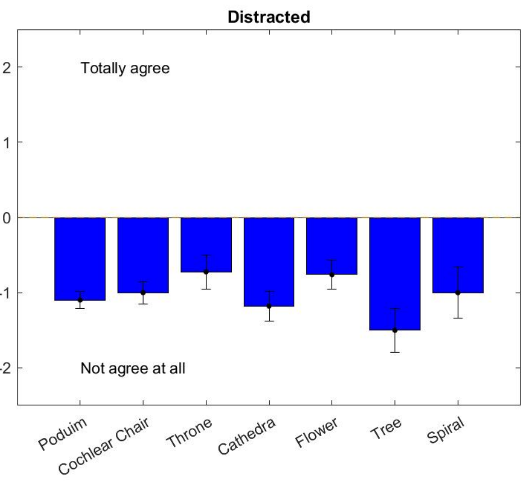

Figure 10. Ratings for the Question: *The vibrations were a distraction from the music.* See figure caption 8 for more information

tion of the music. A simple linear model with the installations as fixed factors, the participants as random effects, and the rating as the dependent variable showed a significant positive effect of the installations ($F(6, 210.9) = 6.71, p < 0.0001$). However, not all installations were equally effective. A post-hoc pairwise t-test comparison (with correction for multiple comparisons) indicated that the *Flower* installation was significantly less effective than all others. In addition, the *Cathedra* was rated significantly more positively than the *Cochlear Chair* and the *Throne*. All other installations (the *Throne*, *Cochlear Chair*, *Three*, and *Spiral*) were rated similarly to each other.

4.2 Question 2: I experienced varied musical elements through different parts of my body

People with hearing impairments often struggle to discriminate different musical parts [7]. Hence, a system that enhances the perception of multiple melodic streams would be greatly beneficial. Figure 9 shows that, on average, all the installations (except the *Flower*) improve participants' music perception, with a significant difference ($F(6, 219.3) = 14, 69, p < 0.0013$). The post-hoc analysis revealed that the *Flower* was rated significantly lower than the other installations. Additionally, the *Spiral* was rated lower than the *Cathedra* and *Podium*. The results suggest that the *Cathedra* device has the potential to help people with impairment to segregate different musical streams.

4.3 Question 3: The vibrations were a distraction from the music.

To avoid sympathy voting, we introduced a negative aspect to the rating system, where a positive evaluation should correspond to a negative rating. Figure 10 shows that, on average, the installations were rated as not distracting to the music, with the lowest score achieved by the *Tree* and the highest by the *Flower*. Although the intercept

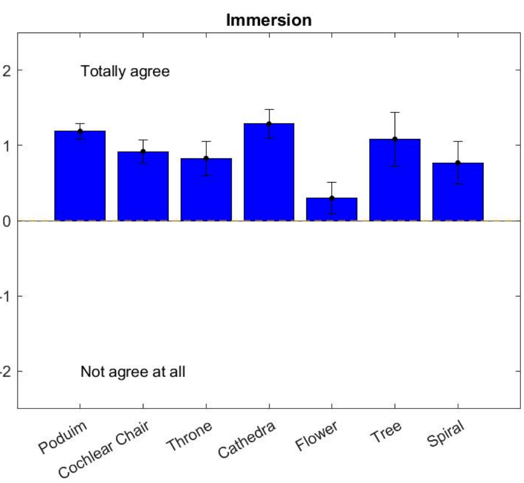

Figure 11. Ratings for the Question: *The vibrations allowed for a more immersive musical experience.* See figure caption 8 for more information

was significantly lower than 0, the overall effect of the installations was not significant ($F(6, 200.4) = 1, 49, p = 0.1824$) due to high variability in ratings. Post-hoc analysis revealed that only the *Cathedra* was rated significantly lower than the *Flower* and the *Throne*.

4.4 Question 4: The vibrations allowed for a more immersive musical experience.

The results supported our hypothesis of full-body installations enhancing music immersion. The top three rated installations, *Cathedra*, *Podium*, and *Tree*, all provided a full-body experience. The hand-only installations, *Flower* and *Spiral*, were found to be less immersive. Statistical analysis showed a significant effect of installations ($F(6, 204.3) = 5.8767, p = 0.1824$).

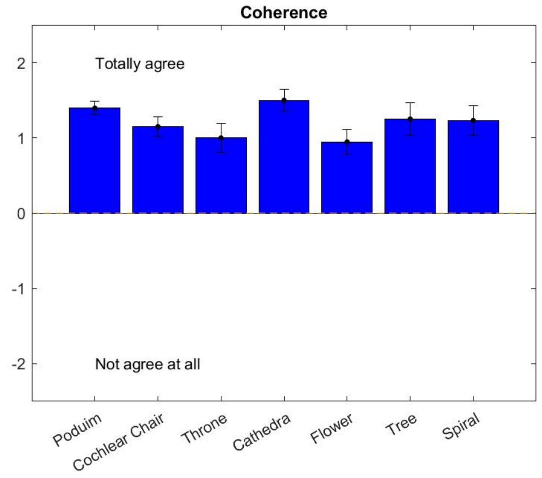

Figure 12. Ratings for the Question: *The vibrations complemented the music.* See figure caption 8 for more information

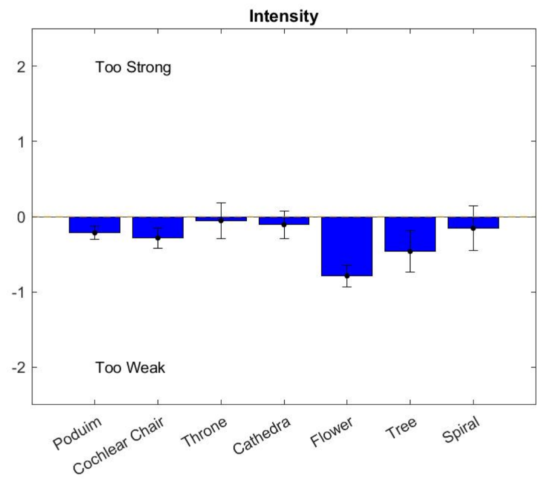

Figure 13. Ratings for the Question: *The vibration intensity was: Not strong enough or Too strong.* See figure caption 8 for more information

4.5 Question 5: The vibrations complemented the music.

We aimed to test if listeners perceived the vibration as a coherent musical expression, as the composers used it as a new means of musical expression. Results in Figure 12 support this hypothesis ($F(6, 210.9) = 6.7079, p < 0.00001$).

4.6 Question 6: The intensity of the vibration

Achieving optimal audio-tactile integration requires balancing audio and tactile intensity to avoid overpowering one sense [8]. A full-time sound engineer was assigned to mix music for this balance. Results from Figure 13 show that, on average, participants judged the vibration intensity as adequate, except for the ”Flower” and ”Tree” installations. These installations were added later in the concert, which may indicate the sound engineer’s lack of familiarity. To enhance future performances, the intensity of these installations should be increased.

5. CONCLUSIONS

The study aimed to design and evaluate a series of vibrotactile installations that respond to specific note ranges of music. Musicians were asked to compose a piece of music specifically for these installations to create a piece that could be heard and felt by the audience. The installations were tested and evaluated through a questionnaire filled out by the audience after each concert. The results showed that the different installations had different efficiencies in transmitting the vibrations of music to the audience. This information will be useful in improving the design of devices to optimize the tactile musical experience, especially for individuals with hearing loss who rely more on touch to enjoy music.

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